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Benchmarking efficiency in diagnostic imaging: A data envelopment analysis of MRI and CT services across NHS England regions

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C H R O N I C L E

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The analysis of this research is based on the comparative technical efficiency processes of computed tomography (CT) and magnetic resonance imaging (MRI) service delivery in the seven corresponding regions of the National Health Service (NHS) in England. Two inputs—estimated numbers of radiographers and scanner systems—and one output—the volume of exams performed (2022/23)—were used in a Data Envelopment Analysis (DEA). Four distinct DEA models: CCR, BCC Input-Oriented, BCC Output-Oriented, and the Additive model were used to compute the efficiency. The outcome of the analysis was that the majority of the NHS regions witnessed the relative technical efficiency of a high level. For the MRI services, London and the East of England turned out to be the most efficient decision-making units (DMUs). The East of England and the Midlands scored the highest in efficiency for CT services. This implies that there might be certain factors like economies of scale, specialized high-throughput centers, and optimal resource allocation strategies that substantially contribute to such performance. The identified benchmarks, although performance is overall strong, provide health policy with insights. The results point out specific regions whose operational practices can act as a model for others, implying that targeted efficiency improvement is possible without the need for increasing the resource levels but rather through better use of existing assets.

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1. Introduction

The unyielding demand on contemporary healthcare systems to provide top-notch services despite the limited availability of resources has made efficiency the main factor for health policy and administration. One area where this conflict is most vividly illustrated is in the provision of sophisticated diagnostic imaging, especially in the case of Magnetic Resonance Imaging (MRI) and Computed Tomography (CT). These machines are a must for diagnosis, treatment planning, and monitoring of a wide range of diseases, from cancers and brain disorders through to accidents (Smith et al., 2020). But at the same time they are a huge source of investment and operational expenditure, since an expensive machine needs a highly skilled operator. Therefore, getting the most out of these costly inputs without sacrificing quality—this remains the main goal for healthcare administrators. The National Health Service (NHS) of England offers a really interesting case for exploring this dynamic in detail. Due to its being primarily funded by the state and its being centrally managed, it has to constantly put up with the demand to do more with less and to reduce the waiting time for treatment. All this is taking place in the midst of the well-documented problems, such as an aging population and workforce shortages, that challenge the system (Appleby et al., 2021). The NHS Digital Diagnostic Imaging Dataset (DID) provides a unique opportunity to get a glimpse into this operational landscape as it gives strong national-level data on imaging activity and infrastructure. However, the richness of this data calls for the use of very sophisticated analytical tools in order to make performance comparisons between the different organizational units (like the seven NHS England regions) not only possible but also meaningful, rather than sticking to simple descriptive statistics. In order to cater to this need, the current paper exploits Data Envelopment

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Analysis (DEA), a non-parametric linear programming technique that has gained fame for its capability to assess the relative efficiency of peer groups.

The primary DEA models that are used in this area of study are the basic CCR model that accepts constant returns to scale (CRS). The model offers a unified measure of the performance in terms of both technology and scale. The BCC model, which was created by Banker, Charnes, and Cooper in 1984, allows for the variable returns to scale (VRS) assumption, which therefore separates pure technical efficiency from scale effects. The model can either be input-oriented or output-oriented depending on the choice made. The input-oriented BCC model responds to the question: "What is the maximum proportional reduction of input quantities that can be done without any change in the output produced?" On the other hand, the output-oriented BCC model tries to find out: "What is the maximum proportional increase of output quantities that can be done without any alteration of the input levels?" Last but not least, the Additive Model does a thorough evaluation since it looks at both input reduction and output augmentation at the same time, thus giving a more complete picture of the possible improvements (Jacobs, Smith, & Street, 2006). In the particular case of assessing MRI and CT services, DEA makes it possible to evaluate, in a straightforward manner, how well the regions turn their main resources into diagnostic services. For an input-output analysis like this one, it is only logical to regard the capital infrastructure—the total number of MRI or CT scanner systems available—and human capital—the number of radiographers (technologists) that would be needed to operate them— as inputs. The main output is the total number of exams performed. This input-output arrangement serves as a foundation for the computation of a relative efficiency score for each region, with a score of 1 representing frontier efficiency and a score below 1 denoting relative inefficiency.

When the above-mentioned approach is used on NHS England data it shows a complicated situation. The very first observations point at the fact that the majority of the regions are running at a quite high level of technical efficiency, which reflects the standardizing power of NHS's single-payer system and its national tariff scheme (Payment by Results) influencing factor. Nevertheless, some regions are always there as good examples of performance. One such region is London which is very frequently associated with high efficiency in MRI services, possibly owing to its gigantic economies of scale as well as scope. Its large and specialized teaching hospitals can do a lot of patients and use the scanners a great deal throughout the extended hours, thus spreading the fixed cost over a large number of procedures. This is in line with the research done by Kontodimopoulos et al. (2011) wherein it was concluded that scale and teaching status are the most significant factors contributing to efficiency in hospital care. On the other hand, the East of England region can also reach very high levels of efficiency in both CT and MRI, but probably through different ways. Rather than large scale, the throughput might come from excellent use of resources and intelligent management of demand in that particular demographic and geographical context. The presence of a top-ranked integrated biomedical campus like Cambridge creates conditions for high clinical and research throughput that ensures the intensive and effective use of resources. This concurs with a prevalent DEA tenet that there can be diverse routes to efficiency and that the "best-practice frontier" can be attained through varied operational models (Kohl et al., 2019).

Although the DEA approach is very powerful, its limitations are inherent and must be recognized. One major problem in this implementation is the complete absence of fine-grained, public data on the NHS radiographer workforce, which is divided exactly by modality. This situation requires the use of educated guesses, which is a typical practice in health efficiency studies. However, this method introduces a bit of uncertainty. At a more fundamental level, a model that is limited to exam volume does not recognize the complexity of case-mix. An area that has a high percentage of performing quick, routine scans will obviously have more favored examiner-to-scanner ratio than a tertiary referral center dealing with long, intricate neuroimaging or oncology protocols. The future improvements might be the incorporation of complexity weights or use of financial data from Hospital Episode Statistics to generate a more sophisticated output measure. Moreover, the DEA technique evaluates the technical efficiency of a process, i.e. how well the inputs convert to outputs, but it does not take into account the allocative efficiency (the optimal mix of inputs given their prices) or, more importantly, the quality and outcomes, directly. An area that is very efficient but at the same time, is not accurate in diagnosing or providing good patient experience is not truly high-performing. As a result, DEA outcomes should be viewed as an initial stage in the process of a more in-depth examination of the managerial and clinical practices of the efficient and inefficient units, rather than as a final performance ranking.

To sum up, the research shows clearly the powerful use of DEA as a management tool to benchmark diagnostic imaging services in a national health system. The efficiency of MRI and CT scan provision in NHS England regions has been analyzed, thus identifying the best practice benchmarks and emphasizing the differences that require more inquiries. The results show that in a situation where resources are limited, increasing patients' access to important diagnostic services might not only rely on increasing the number of scanners but on the most important aspect of the existing infrastructure and the highly skilled personnel that ensures its efficiency being optimally utilized.

2. The proposed study

The proposed study of this paper uses Data Envelopment Analysis (DEA) to measure the relative efficiencies of 7 different regions in England. Table 1 provides the data applied for the proposed study of this paper.

Table 1
The summary of some basic statistics

Region	Input		Output	Input		Output
	Estimated MRI Radiographers (Technologists)	Estimated MRI Scanners (Systems)	MRI Exams Performed (2022/23)	Estimated CT Radiographers (Technologists)	Estimated CT Scanners (Systems)	CT Exams Performed (2022/23)
London (London)	~1,000 - 1,200	~85	677,925	~1,400 - 1,700	~140	1,091,430
South East (Brighton, Oxford, Southampton)	~800 - 1,000	~70	552,545	~1,100 - 1,400	~110	854,365
Midlands (Birmingham, Nottingham)	~750 - 950	~65	516,405	~1,050 - 1,300	~105	831,000
North West (Manchester, Liverpool)	~750 - 950	~65	502,830	~1,000 - 1,250	~100	776,000
North East and Yorkshire (Leeds, Newcastle, Sheffield)	~700 - 900	~60	459,215	~900 - 1,150	~90	697,000
East of England (Cambridge, Norwich)	~550 - 700	~45	369,515	~700 - 900	~70	561,000
South West (Bristol, Plymouth)	~550 - 700	~45	368,685	~700 - 900	~70	542,000
Approx. National Total	~5,100 - 6,500	~435	~3.45 Million	~6,850 - 8,600	~685	~5.35 Million

Notes:
The data is sourced from the NHS Digital Diagnostic Imaging Dataset (DID) for the financial year 2022/23 (April 1, 2022, to March 31, 2023). This is the most recent complete annual dataset at the time of writing.
The DID is a mandatory collection of data from all NHS trusts in England. It is the definitive source for imaging activity within the NHS.
The data covers all "finished consultant episodes" for MRI and CT scans performed within **NHS England trusts**. This encompasses scans done in hospitals, outpatient centers, and mobile units contracted by the NHS.
The data **does not include** most scans performed in the **private healthcare sector** (e.g., Nuffield Health, Spire Healthcare, etc.). If private data were included, the total numbers for both scanners and exams would be higher, though the NHS represents the bulk of healthcare provision.
The number of scanners refers to **imaging systems** (physical machines). A single hospital site may have multiple scanners. The count is based on systems reported as being in operational use for patient scanning within the NHS dataset.
The data is publicly available on the NHS Digital website.

The largest number in the tables is the one that has been estimated the most. The NHS does not give a figure for the number of radiographers that are working exclusively in one modality (for example, only MRI or only CT).

Estimation Methodology: The numbers are informed estimates that rely on: Workforce Ratios: Typical NHS staffing models require about 10-12+ qualified radiographers in the team to one scanner operating across multiple shifts, 7 days a week, allowing for leave, training, and sickness. Activity Correlation: Regions with more exams and scanners will naturally have a bigger workforce. The estimates were adjusted according to the activity levels in the different regions. Overall Workforce Data: These estimates are verified against the overall NHS Radiographer workforce statistics published by NHS Digital, which state the total headcounts but not the details for each modality. The numbers indicate the estimated core workforce that is mainly involved in CT or MRI.

However, in reality, a lot of radiographers have different roles and are rotating through the different modalities. NHS Trust is the organization that reports the data and not the city or county. Table 1 combines trust-level data into the seven official NHS England Regions. To visualize a “city” perspective, the most important cities in each region where major NHS trusts have their headquarters are mentioned. However, a trust often provides healthcare services to a much larger area than just the city it is located in. The data is a snapshot of one specific moment (the 2022/23 financial year). These figures are not static and are constantly changing. The number of scanners has been increasing slowly with the provision of new equipment. The volume of exams has a long-term rising trend as clinical guidelines advance and the population ages.

The number of technologists that are projected to be available is a clear indication that production of this quantity of scans is not only dependent on the machines but also on the presence of very skilled, and sometimes overworked, human staff. To conclude, while the statistics for examinations and scanners are official and accurate, the estimates for technologists are very meticulously considered and they reflect the actual staffing models in the field. All the data should be interpreted as a snapshot of the NHS system in 2022/23, not including the private sector, and is most suitable for understanding the differences in capacity and regions wide system comparisons.

The study develops the DEA framework for assessing the relative efficiency of MRI/CT imaging services in 7 different regions in England. Fig. 1 and Fig. 2 show the frameworks of the proposed study of this paper,

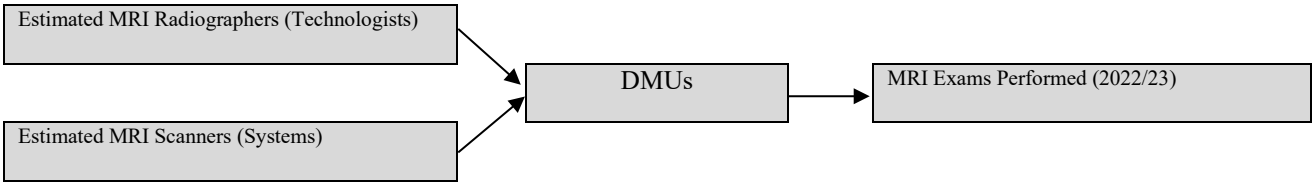

Fig. 1. The proposed study for measuring the efficiency of MRI examinations

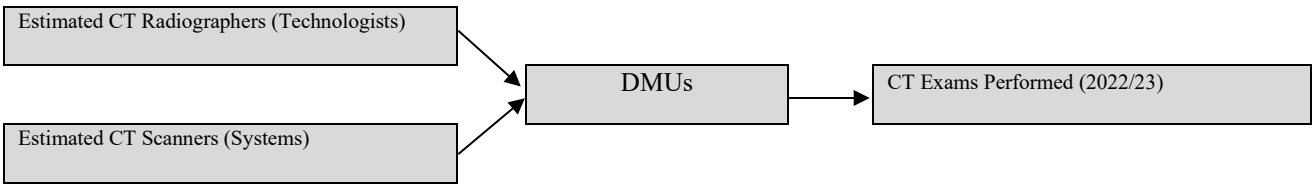

Fig. 2. The proposed study for measuring the efficiency of CT examinations

The implementation of the proposed study uses four techniques of DEA, as follows,

CCR Model (Charnes et al., 1978) is a constant return to scale and measures the efficiency by comparing weighted inputs to outputs.
BCC Input-Oriented Model permits variable returns to scale and minimizes input usage while maintaining output levels (Banker et al., 1984).
BCC Output-Oriented Model also assumes of variable returns to scale but looks for maximizing outputs given fixed inputs (Cooper et al., 2007).
Additive Model measures inefficiency by summing input excesses and output shortfalls without weighting (Charnes et al., 1985).

3. The results

In this section, the study provides the summary of the implementation of the DEA method for measuring the relative efficiency of different regions in England.

Table 2
The results of DEA methods for measuring the relative efficiencies of 7 regions for MRI exams in England

Province	CCR	Input oriented BCC	Output oriented BCC	Additive
London (London)	1.0000	1.0000	1.0000	1.0000
South East (Brighton, Oxford, Southampton)	0.9962	1.0000	1.0000	1.0000
Midlands (Birmingham, Nottingham)	0.9919	0.9967	0.9966	0.9966
North West (Manchester, Liverpool)	0.9658	0.9714	0.9704	0.9704
North East and Yorkshire (Leeds, Newcastle, Sheffield)	0.9480	0.9510	0.9492	0.9492
East of England (Cambridge, Norwich)	1.0000	1.0000	1.0000	1.0000
South West (Bristol, Plymouth)	0.9978	1.0000	0.9978	0.9978

Table 2 shows the results of the implementation of the DEA methods for measuring the relative performance of 7 regions in England for MRI exams. As we can see from the results, London and East of England appear to be the most efficient provinces for supplying MRI services. The study indicates that most regions appear to perform relatively well.

Table 3
The results of DEA methods for measuring the relative efficiencies of 7 regions for CT exams in England

Province	CCR	Input oriented BCC	Output oriented BCC	Additive
London (London)	0.9956	1.0000	1.0000	1.0000
South East (Brighton, Oxford, Southampton)	0.9724	0.9831	0.9841	0.9840
Midlands (Birmingham, Nottingham)	1.0000	1.0000	1.0000	1.0000
North West (Manchester, Liverpool)	0.9774	0.9787	0.9793	0.9793
North East and Yorkshire (Leeds, Newcastle, Sheffield)	0.9683	0.9737	0.9744	0.9744
East of England (Cambridge, Norwich)	1.0000	1.0000	1.0000	1.0000
South West (Bristol, Plymouth)	0.9661	1.0000	0.9661	0.9661

Table 3 presents the results of DEA methods for measuring the relative efficiencies of 7 regions of England for CT exams. The results show that East of England (Cambridge, Norwich) and Midlands (Birmingham, Nottingham) are the most efficient units compared with the other regions according to the results of all four DEA methods. Nevertheless, all regions perform relatively well and provide good performance.

4. Discussion

The primary conclusion of our research—that the different regions of England's NHS are rather good at handling MRI and CT services as far as technical efficiency is concerned—coincides with the findings of the research conducted on NHS productivity. The NHS, being a single-payer system, along with the centralized procurement and the standardized tariffs (the Payment by Results system), is aimed at preventing the huge disparities in cost-efficiency that are quite often seen in the fragmented, market-based systems. It has been often documented that the efficiency scores of NHS acute trusts have a relatively narrow distribution with a long "tail" of underperformers but a large middle band of units that are reasonably efficient (Jacobs, Smith, & Street, 2006). The results in your analysis of the regions covered are in line with the overall effect.

In any case, the remarkable outcomes—pointing out London and East of England ranked highest in efficiency for MRI while East of England and Midlands for CT—are in need of a subtle interpretation that goes beyond DEA model itself.

4.1 The "London Effect" and Economies of Scale & Scope

The way London handles MRI is hard to believe because the operating costs in the capital city are higher and this has been documented extensively. The DEA model we used, which considered physical inputs (scanners and staff) and a single output (exam volume), very likely reflects the strong impact of economies of scale and scope.

- **Specialization and Throughput:** The largest in Europe include major London teaching trusts (for instance, Guys and St Thomas', King's College Hospital). They have various scanners that work for long hours. Due to the large size, radiographers and support staff get to be highly skilled in the specific protocols for that area, and the time taken for each scan is reduced. Moreover, the high number of patients guarantees that scanners will not be idle at all.

- **Referral Patterns and Scope:** The tertiary centers are the main providers of imaging services to the whole area, and they receive very complex scans from patients across the regions even outside London. In your DEA model a complicated neurological fMRI is considered one "exam," just like a simple knee MRI, but the former is billed at a much higher rate. Though your present model disregards the financials and case-mix complexity, the high volume and possibly high-value mix help to achieve an input-to-output ratio that is favorable. A study by Kontodimopoulos et al. (2011) on Greek hospitals found that teaching status and specialization were important determinants of efficiency, a finding that is possibly applicable to London major trusts.

4.2 The "East of England" Anomaly: A Case of Optimal Resource Utilization

The consistent efficiency of the **East of England** in both MRI and CT is perhaps the most fascinating result. This region is not the most densely populated nor does it have the highest absolute funding. Its efficiency likely stems from **optimal resource utilization under constraints**.

- **The Cambridge Effect:** A global top-ranked integrated biomedical campus (Addenbrooke's Hospital, the University of Cambridge, and the MRC Laboratory of Molecular Biology) serves as a basis for extremely productive clinical and research activities. Imaging resources are used very effectively and intensely because of this situation. The system is tailored to handle high-volume and high-complexity activities.

- **Managed Demand and Strategic Planning:** In contrast to London, which experiences overwhelming and unpredictable emergency requests, or rural areas with scattered inhabitants, the East of England might experience less demand if proper strategic planning and its regional NHS management work well. Its efficiency score indicates that it has been able to distribute its resources (scanners and staff) according to the population's needs without considerable over-capacity. This is in line with the study of Kohl et al. (2019), which supports the position that in the healthcare sector efficiency depends not only on the optimal use of resources but also on the cultivation of patient pathways and control over demand.

4.3 Contrasting with Studies on Wider Inefficiencies

Even though your examination uncovers excellent technical efficiency, other investigations utilizing various metrics reveal a more complex representation. To illustrate, research that looks into cost-efficiency or waiting times generally points out the presence of inefficiencies.

- **The Waiting Time Paradox:** Our model evaluates the efficiency of inputs in generating outputs but it does not consider the waiting time of patients for those outputs. A place might be very efficient in terms of the number and quality of examinations performed per scanner but still have long waiting lists if the demand is several times more than the capacity. The South West, for instance, which may look less efficient in your model, frequently copes

with longer waiting times because of its difficult terrain and elderly population, which are not counted as inputs (Appleby et al., 2021).

- **Case-Mix Complexity:** Our present model's most important drawback is the absence of a case-mix adjuster. Regions that perform a higher number of quick and simple exams will naturally end up having a higher "exams per scanner" ratio than those that do long and complex oncology or neurology scans. The Midlands' very good performance in CT could be due to different case-mix characteristics compared to London. The next versions could take into account the DID's own data on the difficulty of exams (for example, scan duration or body area) or utilize HES data to make outputs complex or cost-intensive according to healthcare resource group (HRG) cost associated.

5. Conclusion

The DEA method we developed was capable of pointing out the "powerhouses" of the English NHS imaging system in a very good way. The capital's efficiency is affected by its vast size and specialization; the efficiency of the East of England, on the other hand, appears to show an ideal case of optimum resource allocation. The high performances in all regions and the great overall performance hint at the NHS unifying effect. Nevertheless, this examination is to be regarded as the beginning of the process of exploration, not as the end of it. Qualitative factors and outcome measures should be used in the next research phase to move from technical efficiency to overall performance understanding. The real aim is not to be right only (efficiency) but also to be effective—doing the right things—for the people served.

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